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ADVANCED MARINE TECHNOLOGY. HANDLING  
AND TRANSFER AT SEA SECTION

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Office of Naval Research  
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13 December 1974

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20. cont.

Making a unit compatible with other boat requirements may be the principle design problem. Other resilient and decoupling techniques for personnel transfer between ships and boats were also tried. Resilient methods offer promise of easier and safer boat handling and reduced boat damage. Tests showed that resilient devices greatly reduced shock loads and gave promise of reducing deceleration in alongside operations to a few tenths of a g. This work, sponsored by the Office of Naval Research and the Advanced Research Project Agency, was definitely of exploratory nature to provide insight and some numbers and experience to naval architects. Movies were made to show dynamic action.

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TECHNICAL PROGRESS REPORT  
ADVANCED MARINE TECHNOLOGY  
HANDLING AND TRANSFER AT SEA SECTION

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December 13, 1974

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# HANDLING AND TRANSFER AT SEA

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ABSTRACT

Several installations and tests of special energy absorbing fenders on amphibious boats of from 4 to 300 tons have given insight and design data on possible transfer of aircraft landing technology and concepts to boat handling to obtain safer and more reliable operations in rough seas.

For reasons of design, cost, and credibility surplus aircraft landing gear nosewheel assemblies mounted thwartships from the boats have formed the major starting point for these experiments. Any future optimum design might be much different as the requirements are different and perhaps less severe than for aircraft. Making a unit compatible with other boat requirements may be the principle design problem. Other resilient and decoupling techniques for personnel transfer between ships and boats were also tried. Resilient methods offer promise of easier and safer boat handling and reduced boat damage. Tests showed that resilient devices greatly reduced shock loads and gave promise of reducing deceleration in alongside operations to a few tenths of a g.

This work sponsored by the Office of Naval Research and the Advanced Research Project Agency was definitely of exploratory nature to provide insight and some numbers and experience to naval architects. Movies were made to show dynamic action.

Key words: resiliency, wheels, energy absorption, boat, fender, transfer

## INTRODUCTION

Difficulties in handling heavy objects at sea and operating boats in heavy weather are so great as to frequently cause unsafe operations, damage and cessation of operations. Equally important, these difficulties have frequently closed down progress and hopes in badly needed aspects of sea operations.

There are, however, several kinds of things that give reason for optimism in improvement in this field by, hopefully, fairly simple means. Controlled resiliency appears to be a factor in each.

- (1) Marine animals such as seals and sea elephants swim around rocks in rough weather not only passably, but they frequently appear to do it for fun.
- (2) Weight-conscious aircraft, and particularly carrier aircraft, routinely handle enormous kinetic energies when landing. For example, a 10-ton airplane at 100 knots has the kinetic energy of a 1,000-ton ship at 10 knots, or of a 100,000-ton ship at one knot.
- (3) Highway vehicles have developed suspension systems to reduce the effect of road shock when careening down a rough road and have developed bumper systems to absorb energy from a mild collision.
- (4) Supertanker dock designers have developed new energy absorbing systems to ease docking and loading problems.

It would appear that some combination of these techniques might permit improved comfort, cost, and safety. The carrier aircraft application was chosen as the best analog because it is perhaps the most dramatic, the best developed engineering-wise, and the most readily adaptable for demonstration and training purposes.

Rigid objects that collide will generate very large forces as at least one of the respective masses must come down to zero relative velocity in a very short distance and time. Resilient objects can dissipate this energy distribution over a duration of space and time with a correspondingly lower maximum force and acceleration. In addition, the more resilient equipment is apt to be designed to spread that reduced force over a larger area, thus further reducing maximum loads per unit area and danger of one object either injuring itself or the other.



Fig. 1 shows approach relationships with sloping lines representing constant  $g$  values. As indicated, two circular areas centered on about 4  $g$  represent common deceleration values obtained on carrier aircraft, one in a horizontal direction as a result of tail hook restraint, and one in a vertical direction due to downward thrust on the landing gear. The left circular area represents design criterion for modern auto bumper design to prevent serious damage at 2 to 5 m.p.h. The shaded circular area represents what the writer believes reasonable design objectives for resilient fender-equipped boats.

Fig. 2 plots acceleration (or corresponding force) against stopping distance when estimated for a boat-size object alongside a ship in sea state 4. Comparable estimated curves for sea states 2 and 6 are also shown.

It seemed to the writer rather clear at the beginning of this study that if small energy absorption distances are adequate then a wide range of simple schemes or materials are available for distances say out to six inches, and that from six to 12 or 15 inches, quite specialized and perhaps novel fenders would be required. If distances appreciably greater than a foot are involved, it is probable that the design will end up with classical construction and large size.

Trying to decide the category of equipment that might be needed for a given application or sea state was considered to be one objective of this study.

Fig. 3 is a somewhat over-simplified nomogram showing relations between ocean wave characteristics for different sea states. The shaded area represents typical trade wind situations that often constitute the dividing line between when it is practical and impractical to conduct small boat operations. Of interest are line 9 representing the wave velocity and line 10 representing the orbital particle velocity near the surface.

The principal method to be used is to utilize surplus aircraft nosewheel assemblies with full castering capability and with their oleo struts as horizontally-mounted bow and stern fenders sticking out from the side of the boat as in Fig. 4 and later figures. The contemplated significant tests were:

- 4a -- to see if a boat could comfortably and safely lay alongside a ship
- 4b -- how well could a boat approach a ship to assume an alongside position

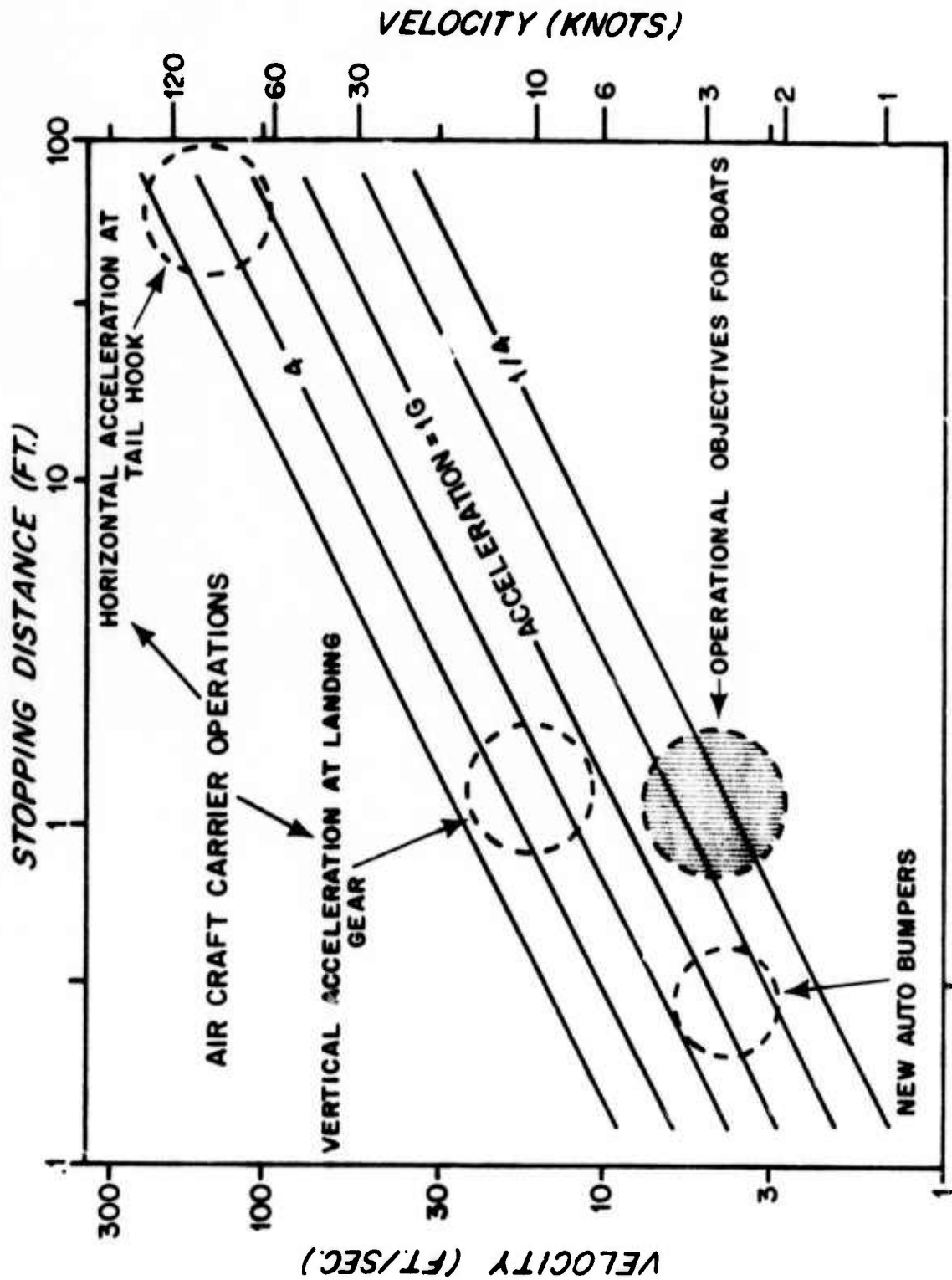


Figure 1. Typical Acceleration Values for Aircraft, New Auto Bumpers, and Well Fendered Boats.

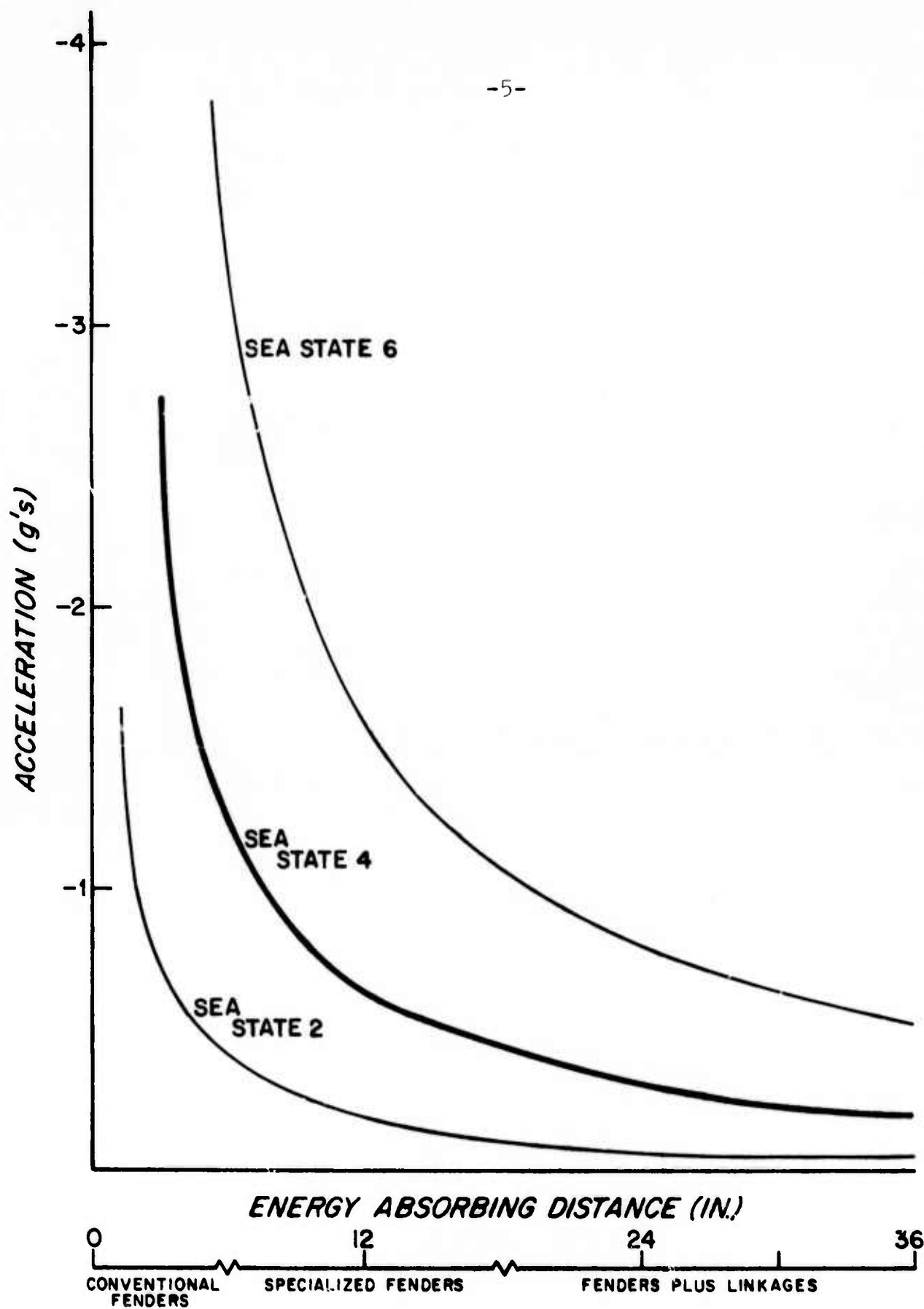


Figure 2. Rough estimate of acceleration versus energy absorbing distance for craft the size of an M-6 in sea states 2, 4 and 6.

# WIND WAVES AT SEA

1	WIND VELOCITY	KNOTS	4	5	6	7	8	9	10	20	30	40	50	60	70
2	BEAUFORT WIND AND DESCRIPTION	1	2	3	4	5	6	7	8	9	10	11	12	13	14
3	REQUIRED FETCH IN MILES	FETCH IS THE NUMBER OF MILES A GIVEN WIND HAS BEEN BLOWING OVER OPEN WATER	50	100	200	300	400	500	600	700					
4	DURATION IN HOURS	DURATION IS THE TIME A GIVEN WIND HAS BEEN BLOWING OVER OPEN WATER	5	20	25	30	35	40	45	50	55	60	65	70	75
IF THE FETCH AND DURATION ARE AS GREAT AS INDICATED ABOVE, THE FOLLOWING WAVE CONDITIONS WILL EXIST. WAVE HEIGHTS MAY BE UP TO 10% GREATER IF FETCH AND DURATION ARE GREATER.															
5	WAVE HEIGHT	CREST TO TROUGH IN FEET	1	2	3	4	5	6	7	8	9	10	11	12	13
6	SEA STATE AND DESCRIPTION	1	2	3	4	5	6	7	8	9	10	11	12	13	14
7	WAVE PERIOD	SEC.	1	2	3	4	5	6	7	8	9	10	11	12	13
8	WAVE LENGTH	FEET	20	40	60	80	100	150	200	300	400	500	600	800	1000
9	WAVE VELOCITY	KNOTS	5	10	15	20	25	30	35	40	45	50	55	60	70
10	PARTICLE VELOCITY	FEET/SEC.	2	3	4	5	6	8	10	12	14	16	18	20	22
11	WIND VELOCITY	KNOTS	4	5	6	7	8	9	10	20	30	40	50	60	70

This table applies only to waves generated by the local wind and does not apply to swell originating elsewhere. WARNING: Presence of swell makes accurate wave observations exceedingly difficult.

- NOTE: (a) The height of waves is arbitrarily chosen as the height of the highest 1/3 of the waves. Occasional waves caused by interference between waves or between waves and swell may be considerably larger.
- (b) Only lines 7, 8, and 9 are applicable to swell as well as waves.
- (c) The above values are only approximate due both to lack of precise data and to the difficulty in expressing it in a single easy way.
- (d) Below the surface the wave motion decreases by 1/2 for every 1/9 of a wave length of depth increase.
- (e) Observations and comments leading to increased accuracy and usefulness are desired.

Figure 3. Shaded area indicates wave conditions of particular interest.

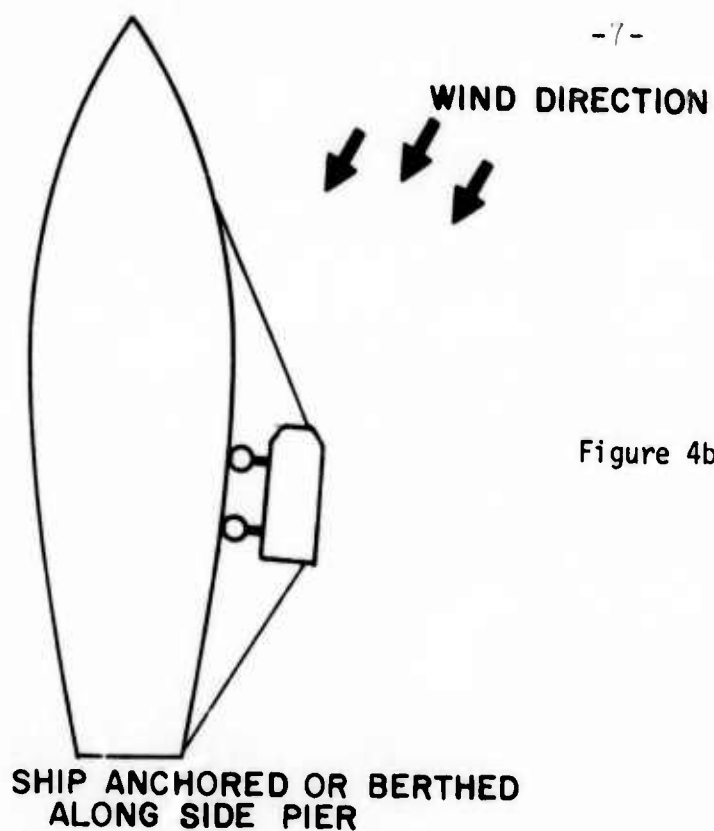


Figure 4b. Approach Test Schematic.

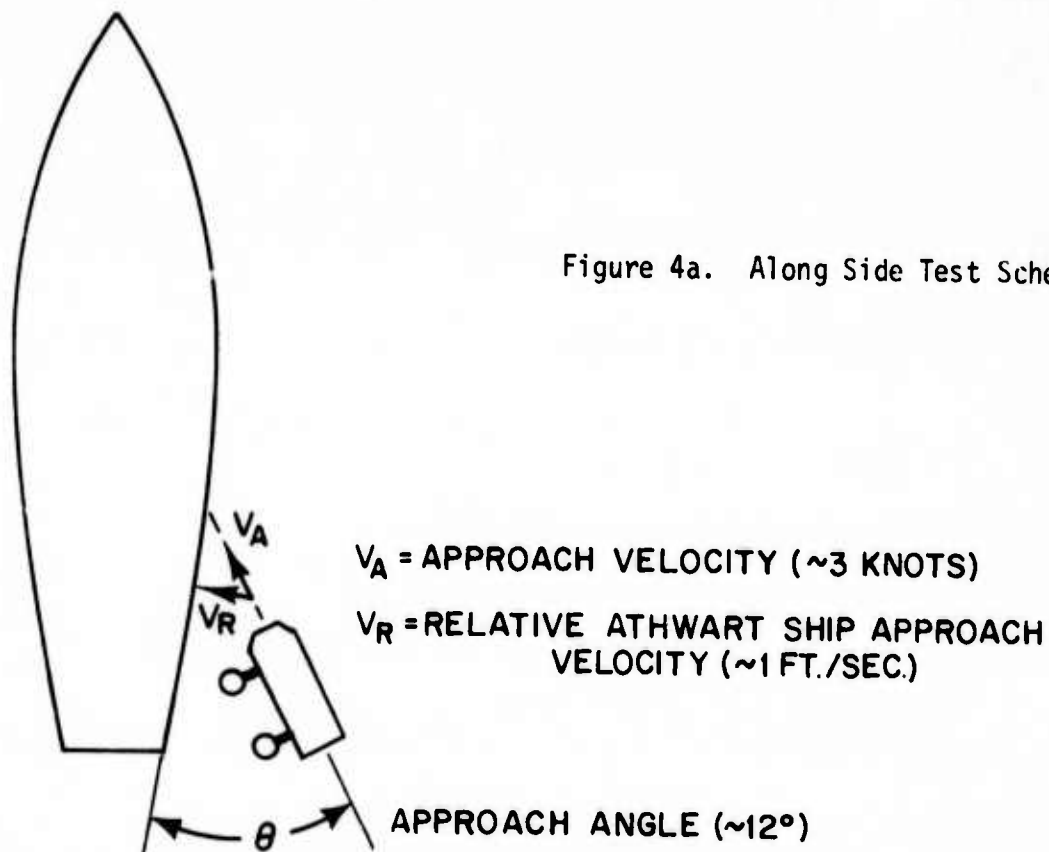


Figure 4a. Along Side Test Schematic.

Nearly all of the tests were variants of these two main patterns.

Fig. 5 represents a second objective of the study that is to see if resilient floats, boats, etc. could be mechanically coupled to the ship with gangways and ladders, but with sufficient decoupling by mechanical linkages and swivels to be operable in significant sea states. Two examples of this type of linkage are a dentist's drill and the hinged ladder on a floating dock.

No formal attempts were planned to design new, optimum or perhaps even reasonable equipment for operations. The limited funds were devoted to try and establish or verify operational principles and limitations relating to a particular problem of two interacting bodies on a rough sea. It was believed that the key was to see if the aircraft landing problem was a reasonable operational analogy.

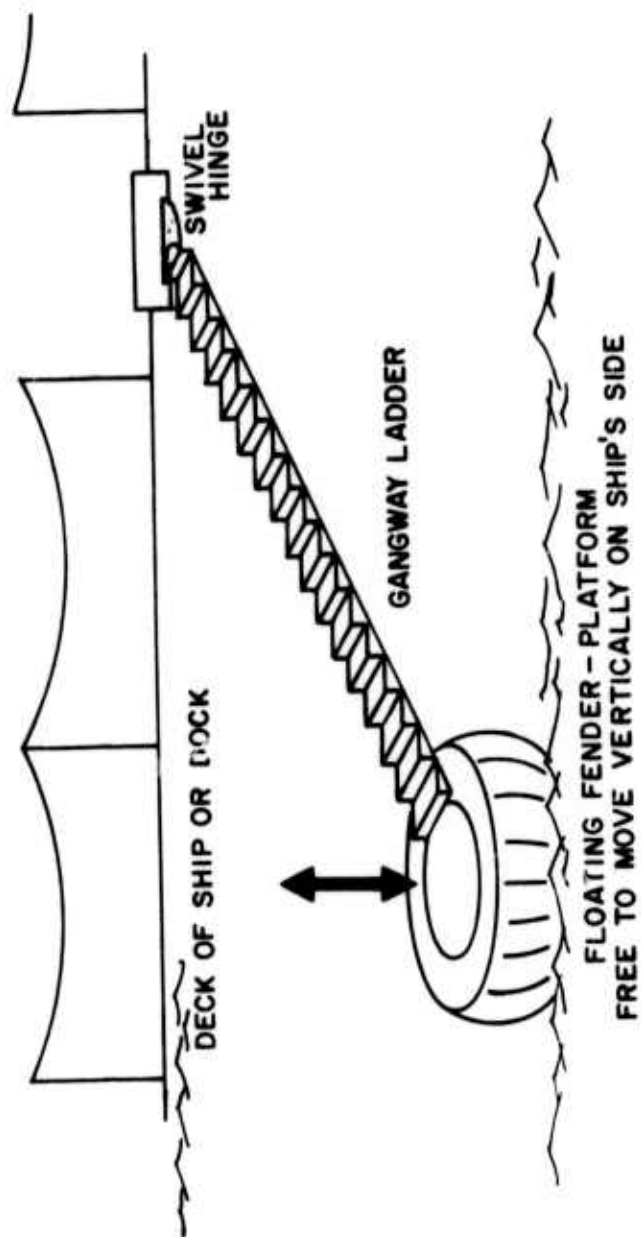


Figure 5. Floating over-the-side gangway, fender and landing platform free to move vertically along ship's side.



## HISTORY AND APPLICATIONS

The problem of handling small boats from ships has been a serious one throughout seafaring history. Whalers and fishermen evolved lightweight boats, had great skill, but suffered numerous casualties. Numerous specialized davits have eased getting boats into or out of the water but have not helped the alongside situation. Limited experiments with fenders have usually ended up with the fender gradually being discarded.

The use by old whalers of putting dead whales between ships and of modern whalers and fishermen who put extremely large rubber fenders between themselves and their mother ship is very pertinent to this problem. However, their fenders have generally been deemed too bulky for most military and civilian applications.

A chief on FRANCIS MARION reported that in about 1955 the (DD-466) USS RADFORD in the Pacific had incorporated rollers into the side of their whale boat and improved its handling characteristics. He also reported that this was a subject of considerable correspondence with BuShips. This is probably typical of many instances where good work was done but has not become part of an overall plan of improvement.

Numerous handling efforts have been based around the handling of small submersibles and various salvage operations.

Still more recently the problem of docking supertankers has caused many more marine energy absorbing techniques to be developed. These commercial equipments include at least one type that combines resilient tires used with vertical axles mounted on a resilient base (Firestone Barleigh).

All these developments seem pertinent to many marine problems and provide another pool of expertise and interest.

Several years ago the U. S. Coast Guard and the writer started experimenting with aircraft wheels and shock absorbers on a three-ton, 24-foot Coast Guard boat and constructed large resilient buoys as one part of a larger program to see if more practical buoys and buoy tenders could be developed. The present work with sponsorship by the Office of Naval Research and the Advanced Research Project Agency with the excellent cooperation from the Commander Amphibious Forces, Atlantic, is an extension of those investigations.



The primary purpose of this contract was to extend previous investigations to larger size boats, to get involved with the fleet and some of their real problems, and to start getting information for preliminary design considerations. Because Amphibious Force problems were the most obvious and they have been the most cooperative, their concerns have dominated the work. In fact, budget expenditures were intentionally kept at a minimum for the first year until bona fide cooperative tests with the fleet could be arranged.

Examples of other possible applications for specialized resilient fendering are:

- (1) Protection of delicate air-cushion vehicles, particularly during their test and evaluation phase. This application is perhaps the closest to the aircraft application.
- (2) Working alongside ships.
- (3) Operating within well deck of amphibious ship.
- (4) Handling of small submersibles.
- (5) Handling of large or heavy instruments.
- (6) Handling of experimental sonars, etc.
- (7) Liberty boats during adverse weather conditions.
- (8) Perhaps the most important is to hopefully encourage the use of large and adequate equipment that is needed to solve many sea-going problems.

PHIBRON TEN TESTS, FEBRUARY, 1973

The first opportunity to work with Navy ships was offered by Captain Kent Carroll, COMPHIBRON TEN, during spring amphibious exercises off Vieques Island on an experimental basis, not to interfere with amphibious training. Time did not permit preparing any special equipment or even mounting existing equipment on the respective boats prior to sailing. However, a truckload of aircraft landing gear assemblies, floats, and equipment along with two surplus truck rear ends from the Norfolk Navy Salvage Yard were put aboard at Norfolk.

Dr. Vine of Woods Hole met the Flagship FRANCIS MARION (LPA 249) at Roosevelt Roads, and the installations were designed and installed onboard different ships while anchored off Vieques.

Tests on 4-ton PL

The two S-2 nosewheel assemblies that previously had worked so well at Woods Hole on the USCG 24-foot-long, 3-ton workboat were installed on a 4-ton PL boat of the FRANCIS MARION (Fig. 6 and Fig. 7). The S-2 assemblies were very satisfactory for the PL and while somewhat large for the low sea states encountered, they might have been appropriate for heavy weather work. In any case, the PL was used a great deal alongside all the ships and spent some time in the well of the PLYMOUTH ROCK.

Although the pair of 8 x 20" tires would easily caster and ride over bumps, hollows, or projections of 6 to 8 inches, an occasional missing board in the side of the well deck would act as a chuck hole that caught the wheels and stopped the boat short.

The wheel assemblies were bolted to 1/4-inch steel plates that were welded to the fore and aft end of the PL deck. Several times the 7/8-inch steel rod bolts were bent with no apparent effect to the wheels, oleo struts, or mounting plates. The tire pressure was reduced to about 20 pounds, and the oleo air pressure to about 50 pounds. Even so, it was rare that a tire was appreciably flattened or that the oleo strut was bottomed.

However, the tests suffered from the weather being too calm. Sea states 1 and 2 were too low to properly evaluate gear designed to succeed or fail at higher sea states. Various maneuvers were conducted as in Fig. 4a and 4b to simulate significant impact forces. Approaches on the side of the ship could be made up to 10 knots speed with 20° closing angle, and the boat would run along the ship's side or come clear as desired with no bothersome shock or noise. The maximum energy absorbing distance for the S-2 assembly was about four-inch tire compression plus 13" oleo compression.



Figure 6. PL alongside resilient float-fender and articulated gangway on EL PASO. Feb. 1973. PhibRon Ten.





Figure 7. PL with S-2 nose-wheel assemblies in well deck.  
Feb. 1973. PhibRon Ten.

Unfortunately we were unable to get additional S-2 assemblies for either that trip or later.

#### Tests on 300-ton LCU

PLYMOUTH ROCK (LSD-29) carried a 300-ton LCU which was equipped on one side near the bow and near the stern, with the after portion of a 5-ton truck chassis with dual wheels, tires, and springs. These assemblies were welded to the side of the LCU with the axles running fore and aft to facilitate rolling vertically up or down the side of the mother ship. Again for several days the weather was too calm to obtain a very significant test other than to note that they clearly worked, there was no problem or noise in staying alongside. An operational plus was that the LCU could move further up under the flared bow than with normal fendering. Fortunately the rig was left on the LCU for some time, and her Captain later reported that he was favorably impressed by the performance and potential under more realistic sea conditions.

The lack of castering wheels to accommodate motion from any direction was noted and felt to be a loss. However, it was believed to be better to have energy absorbers in one direction than none at all.

#### Floating Gangway Tests

EL PASO (LKA 117) rigged the floating resilient gangway like the schematic of Fig. 5 and the photograph of Fig. 6.

The regular gangway ladder was lowered to about 10 feet off the water and secured at that height. A second lightweight aluminum gangway was rigged as a hinge from the bottom of the regular fixed ladder to the top of a large rubber tire-fender-float. This bottom assembly rode vertically with the waves, was free to surge in or out a bit, and acted as a very large fender-platform that was a convenient height from which to transfer between a boat and the ladder.

Regrettably the seas were only about two feet high so the action and utility of this rig in rough seas could only be conjectured. However, many of the officers, sailors, and marines were favorably impressed that such a system looked very promising and attractive compared to using a cargo net for embarkation.

Clearly the writer learned a great deal about the needs and problems of the amphibious forces plus the difficulty of making significant improvements with any single simple device.

Perhaps the most rewarding part of this trip was the generally high interest and cooperative spirit of "it might help us, let's try it" attitude of many of the officers, chiefs, enlisted men of both the ship's force and of the marines.

PHIBRON TWO TESTS, FEBRUARY, 1974

A second opportunity to work with the fleet during training operations and to extend earlier experiments to the larger 120-ton M-8 landing craft was arranged by Captain Carroll and Captain Space of COMPHIBLANT. Design and installation of equipment was arranged through the cooperative effort of the squadron engineer Lt. Cmdr. James and Cmdr. O'Donnell, Commander of the AMSU support facility at the amphibious base.

The program was most fortunate in having Mr. Clifford Stevens of the U. S. Naval Ship Research and Development Center at Annapolis work with us in the planning stage and participate in the sea tests. Mr. Stevens' long familiarity with the technical and equipment design aspects of amphibious operations helped make the tests as useful as possible.

Instructions from PHIBLANT Staff to Captain Merrill, COMPHIBRON TWO, included the request to see if such fendering mechanisms might improve the safety, maneuverability, and stability of landing craft alongside any ship or within the wells of amphibious ships. Also, do tests with larger boats extrapolate logically from earlier tests with small boats, and will the tests suggest other techniques or operational uses?

Because of the active work schedule of the boats prior to these tests, some units became broken during routine well operations. On the LCU they had to be removed so as to not interfere with well operations of other boats. While this was unfortunate for these particular tests, it strongly emphasized the need for effectiveness and compatibility of fendering devices in the well.

M-8 Tests

The principal test vehicle turned out to be the 120-ton M-8 equipped with KC-97 nosewheel assemblies (Fig. 8, 9,10).

Fortunately the weather was much more cooperative than the previous year, and operations with the M-8 were conducted in normal trade winds of 12-20 knots and 3-to 5-foot seas. In all cases, the ships were at anchor.

The M-8 was tested alongside SHREVEPORT both laying alongside and making approaches as shown in Fig. 4. The loss of one engine prevented testing some aspects of maneuverability, but did force experience with the important aspect of operating under frequently encountered handicaps.

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Figure 8. KC-97 assembly on 60 ton M-8 alongside Shreveport (LPD-12). Sea state three. PhibRon Two. Mar. 1974.



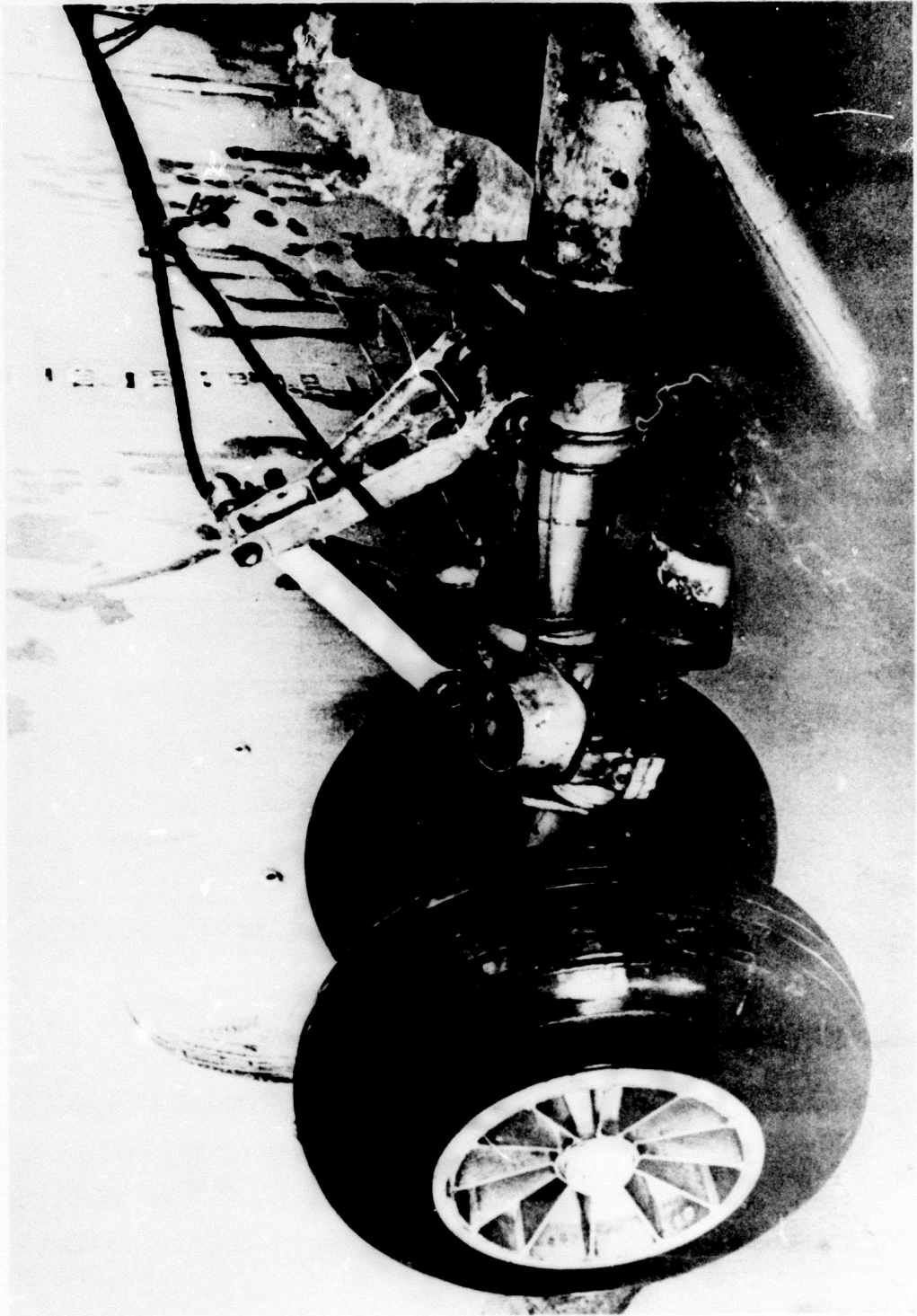


Figure 9. Typical casting action skidmarks of KC-97 nose-wheel assemblies on M-8 alongside Shreveport. Sea state three. PhibRon Two. Mar. 1974.

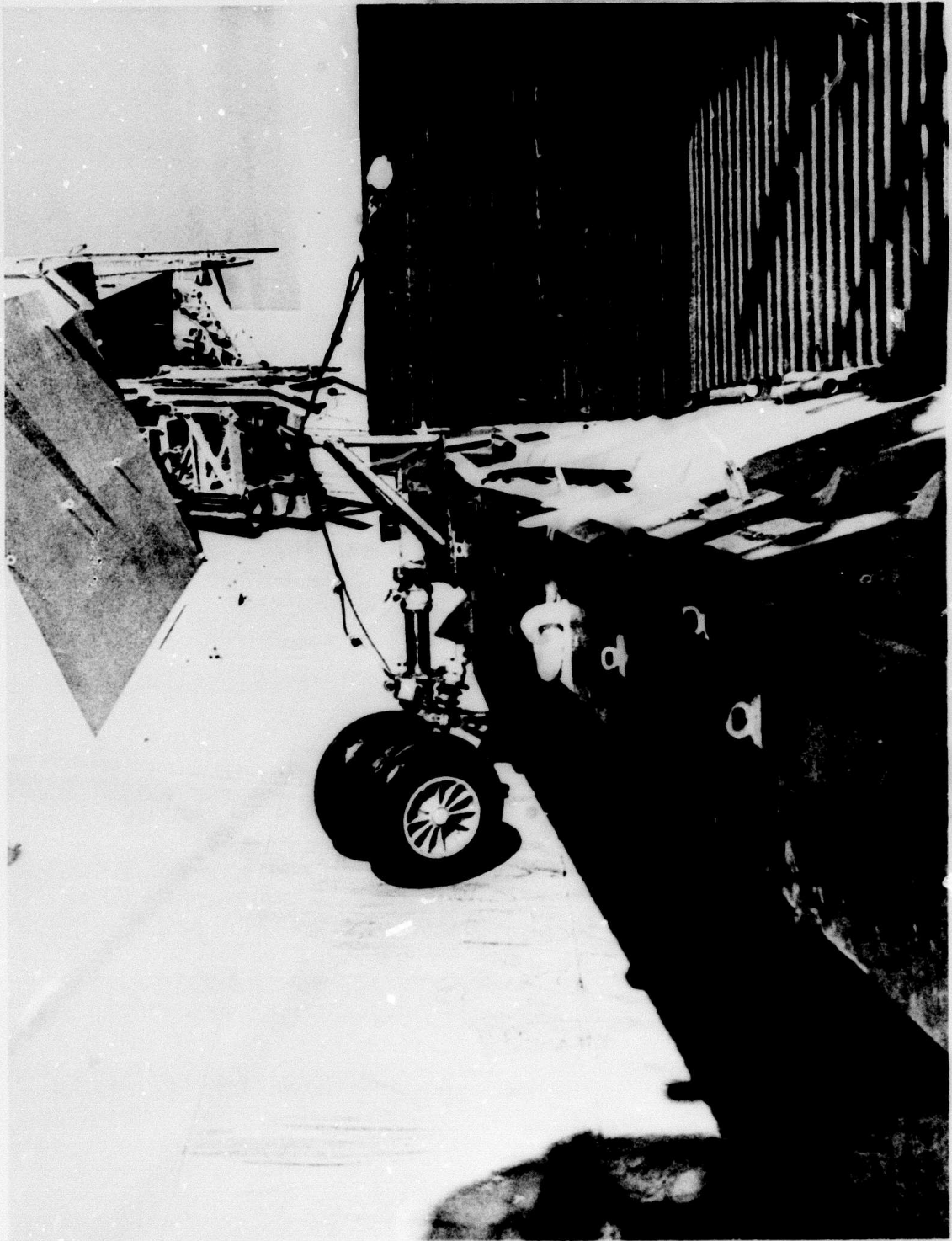


Figure 10. KC-97 nose-wheel assembly on M-8 alongside Shreveport.  
PhibRon Two. Mar. 1974.

Laying alongside on painters fore and aft or operating with power and riding on one spring line was tried several times. The M-8 and the fenders behaved very well. Of particular note was the quietness and smoothness, quite unlike the frequent crash and shock encountered when ordinarily laying alongside. Safety-wise, crew members did not have to concern themselves with fendering problems so they did not have to put themselves in the frequently dangerous position of handling or readjusting fenders. In addition, the low g aspect of cushioned contact permitted an unusual relaxation aboard the M-8 as indicated in Fig. 8 by the relaxed walking position of the crewman when laying alongside SHREVEPORT in 3-to 5-foot seas.

The dual-wheeled KC-97 gear generally castered very well. The occasional failure to caster presented little problem on smooth surfaces but resulted in jamming on projections. Both Fig. 9 and 10 show the action and the tire skid marks on the side of the ship. The overhanging projection shown in Fig. 8 was rolled over many times, but once near the end of the test period it jammed, broke the mounting rig on the M-8, and stopped the test. This demonstrated about how much abuse could be taken.

The front oleo had 200 psi pressure in it which was just about right. The rear oleo strut had leaked to about 100 psi which fortunately was also about correct because the stern of the boat never seemed to move towards the ship as rapidly as the bow. The tire pressures were only 35 psi and seemed appropriate for the work. Hence, the aircraft assembly was obviously working at only a fraction of its designed maximum compression load. The side thrust capacity, however, may have been more severely taxed.

When making runs into the side of SHREVEPORT, approach speeds ranged from three to 5 knots and approach angles about  $80^\circ$  at the higher speeds and  $15^\circ$  at the lower speed. Under both of the more extreme conditions, the bow strut would compress most of its 14 inches and the tires would compress 4 or 5 inches. It appeared that even just the castered wheels without the struts would have been a big improvement and might be a reasonable solution.

In all of these approaches, the coxswain had much more maneuverability and control than he used to as a result of the shock absorber installations. Clearly boats so equipped will provide coxswains with new opportunities as well as a few new problems.

The KC-97 units appeared to be adequately sized for the M-8's and would probably have worked well on the 300-ton LCU's. It was unfortunate that the LCU installation was damaged when in the stowed position in the well. Time and lack of proper spares did not permit it to be made operable for these tests.

Operations in the well deck are much more complex and demanding than on the outboard side of the ship where space permits more extended systems and motions are slower. Factors in the well may define the most severe limiting design criteria for future systems. However, they should not restrain design for craft to be used outboard or with merchantmen.

A hinged gangway ladder with floating resilient platform was made on SHREVEPORT from surplus equipment found at Roosevelt Roads. It was capable of demonstrating the principle and the action in a seaway but was too jury rigged to safely use. Again, however, many amphibious personnel were intrigued by the potential of some type of articulated-floating-loading platform.

Captain Merrill and many members of his staff provided great encouragement and experienced insight on how things might be done to ease or improve their operational problems.

As in the previous tests, a cooperative Navy combat photo crew recorded aspects of the tests in stills and movies.



NORFOLK TESTS, 1 AUGUST 1974

The third segment of field work was at the amphibious base at Little Creek, Virginia, on 1 August 1974. The objective was to obtain quantitative numerical data from a 60-ton M-6 boat whose energy absorbers had been instrumented for stress, strain, and acceleration. The tests were conducted cooperatively with Lt. Cmdr. Frank James of PHIBRON TEN Staff, Dr. Kenneth Morris of the Norfolk-based Explosions Research Division of the Naval Ship Research and Development Center who had instrumented the assemblies, and Dr. Allyn Vine of the Woods Hole Oceanographic Institution.

The M-6 landing craft was equipped with deck-mounted, single-wheel, fully-castering, nosewheel assemblies (Fig. 11) one mounted about 10 percent aft of the bow and one 10 percent forward of the stern as in other installations. The Strain gages were installed by UERD and were in a mounting substructure to measure the thwartship forces. The accelerometer was mounted to measure the thwartship acceleration of the boat.

Because ship time at sea was not available, runs were made alongside the FORT SNELLING while at the pier. The side of the ship had sufficient projections to amply test the castering characteristics of the assembly and the general reactions of the wheels, struts, and boat. All these appeared to be similar to previous tests on ships in a seaway.

Several check-out runs showed that approach speeds of 2 to 4 knots at approach angles of  $10^{\circ}$  to  $15^{\circ}$  were operationally logical and should provide the most useful data. Some dozen approach runs were carried out to gain measurements and additional insight.

The qualitative information indicated that:

- (1) The general behavior of the wheels, struts, and boat was similar to other installations, both larger and smaller.
- (2) While the  $12^{\circ}$  caster angle or 2 1/2-inch offset of the castered wheel was sufficient when against nearly vertical portions of the hull, it was insufficient for rougher or sloping portions, or if the M-6 had rolled appreciably. These tests further substantiated that castered assemblies for this type of marine work probably need 2 or 3 times the effective castering angle used in aircraft practice.

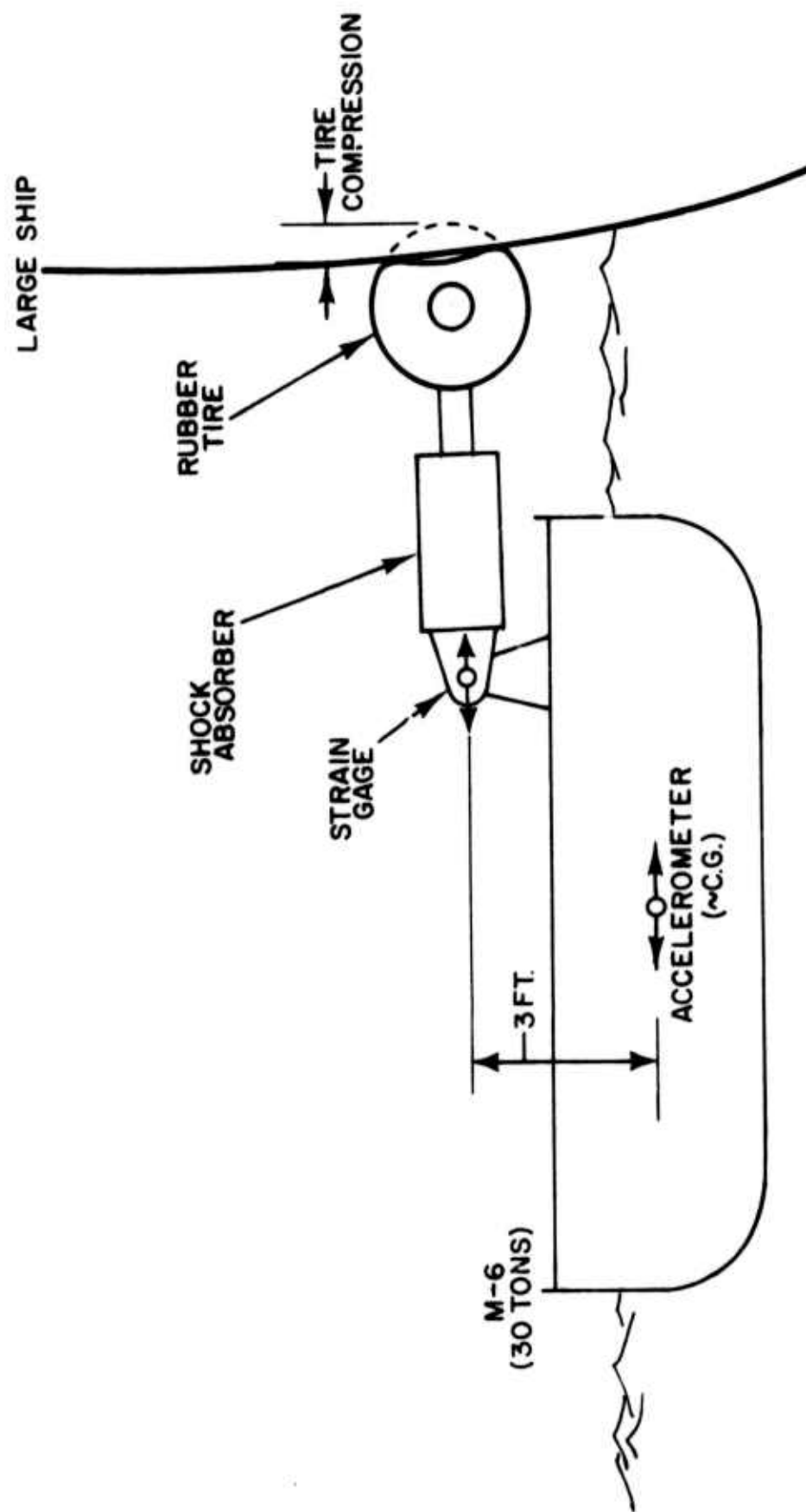


Figure 11. Schematic for August 1974 Tests at Norfolk.

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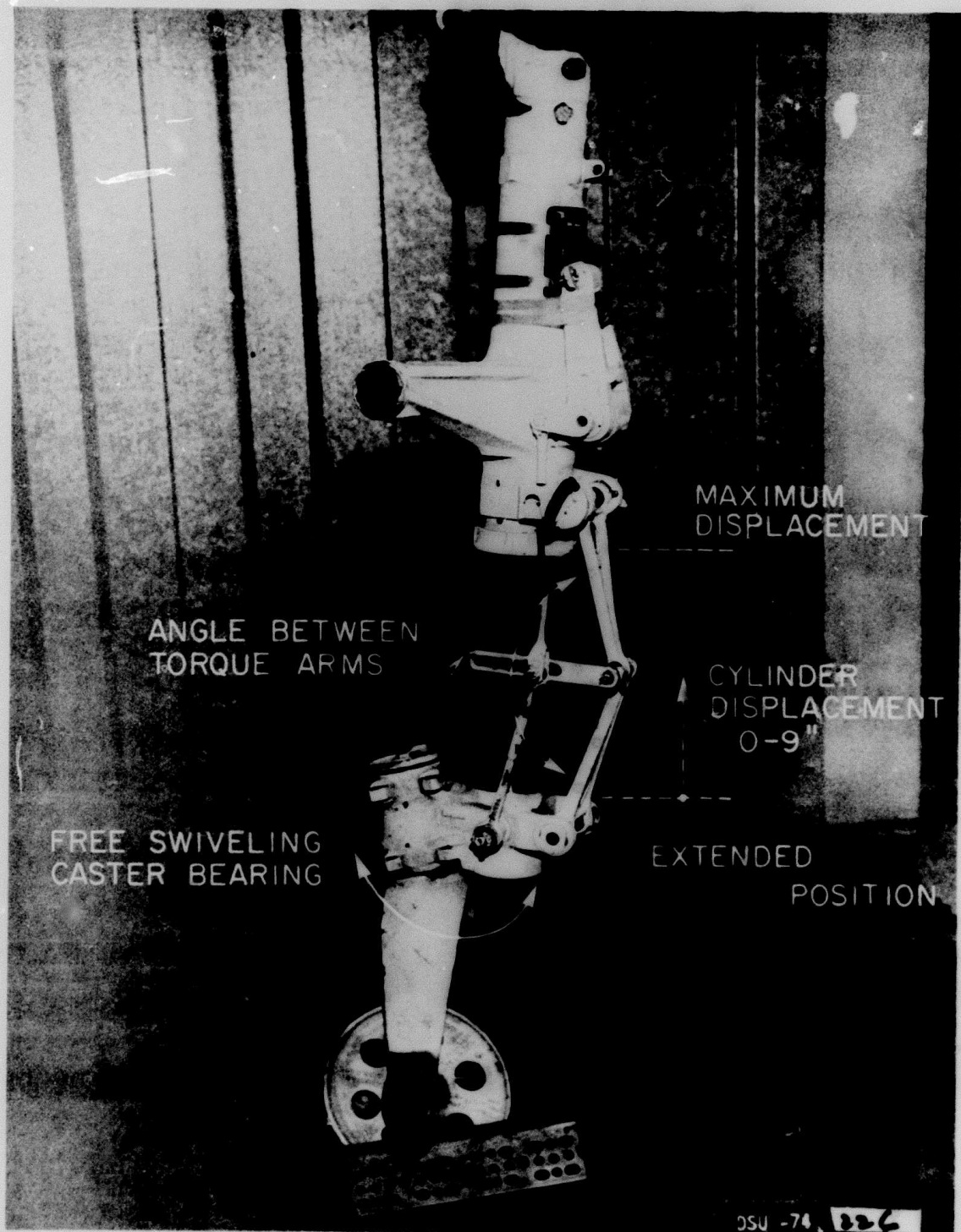


Figure 12. One of two aircraft nose wheel assemblies installed horizontally on M-6 deck for harbor tests at Norfolk, Va. 1 August 1974.

- (4) Any sliding translational motion for marine work would need more suitable bearings and construction for side loads than a conventional aircraft strut.
- (5) Most of the runs gave satisfactory stress-strain records. Maximum force values on the bow assembly seemed to be reasonably consistent with the example shown which was a little over 5,000 pounds.
- (6) As in previous tests, the loads on the forward assembly were generally several times greater than on the after wheel. This seems to be partly due to the bow being shallower draft and more motion conscious and also because the bow will generally be used as a fender to protect the stern and to keep the stern outboard.
- (7) The estimated accelerations of 2/10 to 4/10 g were of no physical concern to the operators and in fact were far less than when coming alongside without fendering. They were also consistent with the 0.4 g obtained in the measured example.

The data taken by the Underwater Explosives Research Laboratory at Norfolk is being incorporated by them into a separate report. They have kindly furnished a set of original data curves from the bow wheel assembly during one typical run as shown in Fig. 13. From that data and associated calibration curves we have derived and interpreted:

- (a) the horizontal displacement-time curve shown in Fig. 14
- (b) the rapid oscillations of acceleration in Fig. 13c represent structural vibrations that are of secondary interest to us at this time
- (c) the average acceleration shown in Fig. 13c rises from zero at  $T = 0$  to about 0.4 g at  $T = 0.6$  seconds and then falls back to zero at about 1.6 seconds

Curve No. 14 shows the relative distance between the boat and the axle of the shock absorption wheel after impact. The addition of a correction for tire compression (approximately 1" at maximum stroke) yields the relative distance between the ship and the boat.

The asymmetry of the curve about a vertical axis through the point of maximum displacement gives an indication of the viscous energy absorption capability compared to the spring-like storage capability of the landing strut as used. The air pressure component of the strut and tire forces acted as an approximately linear spring, producing the greatest force at



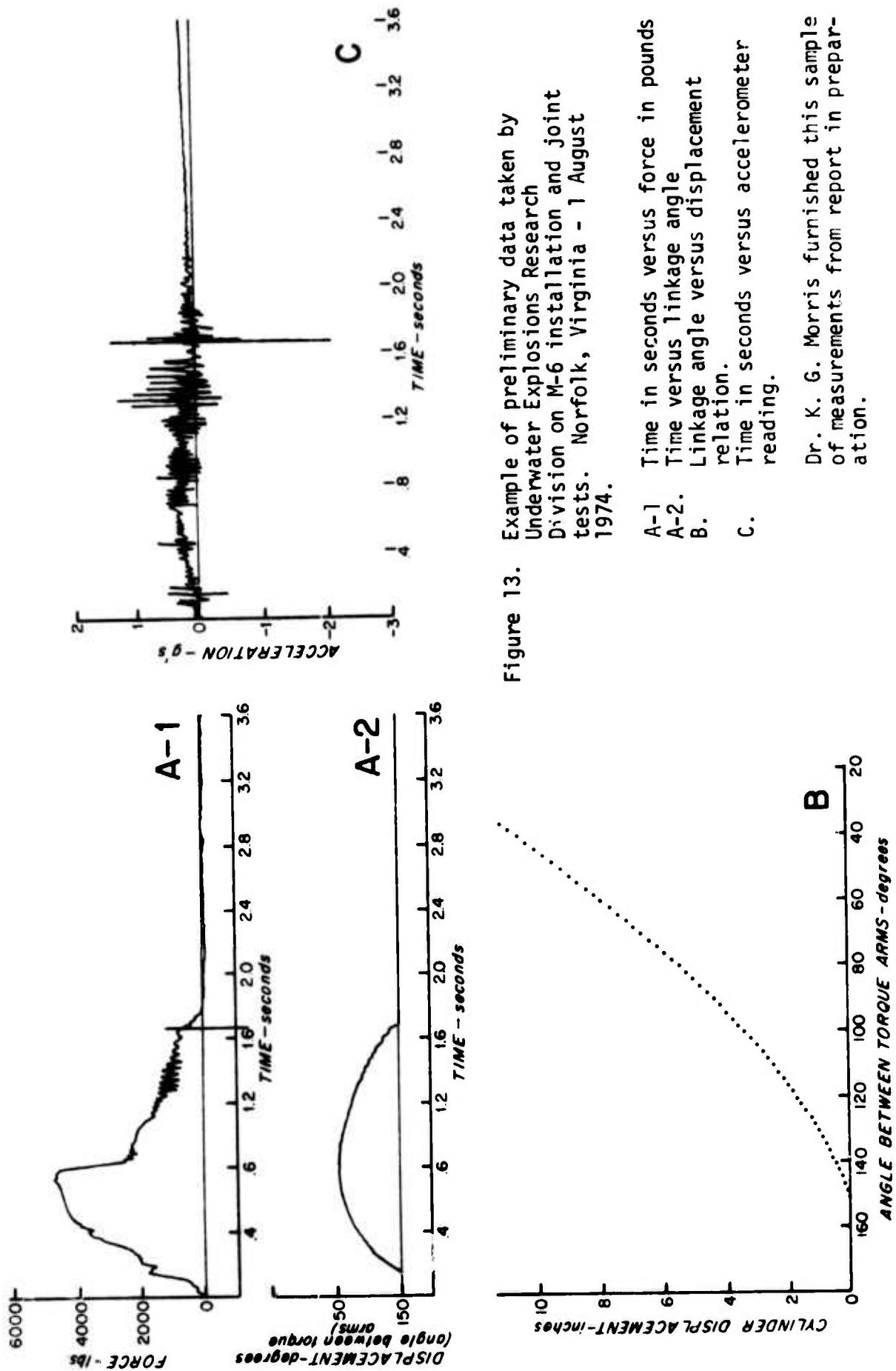


Figure 13. Example of preliminary data taken by Underwater Explosions Research Division on M-6 installation and joint tests. Norfolk, Virginia - 1 August 1974.

A-1 Time in seconds versus force in pounds  
 A-2. Time versus linkage angle  
 B. Linkage angle versus displacement relation.  
 C. Time in seconds versus accelerometer reading.

Dr. K. G. Morris furnished this sample of measurements from report in preparation.

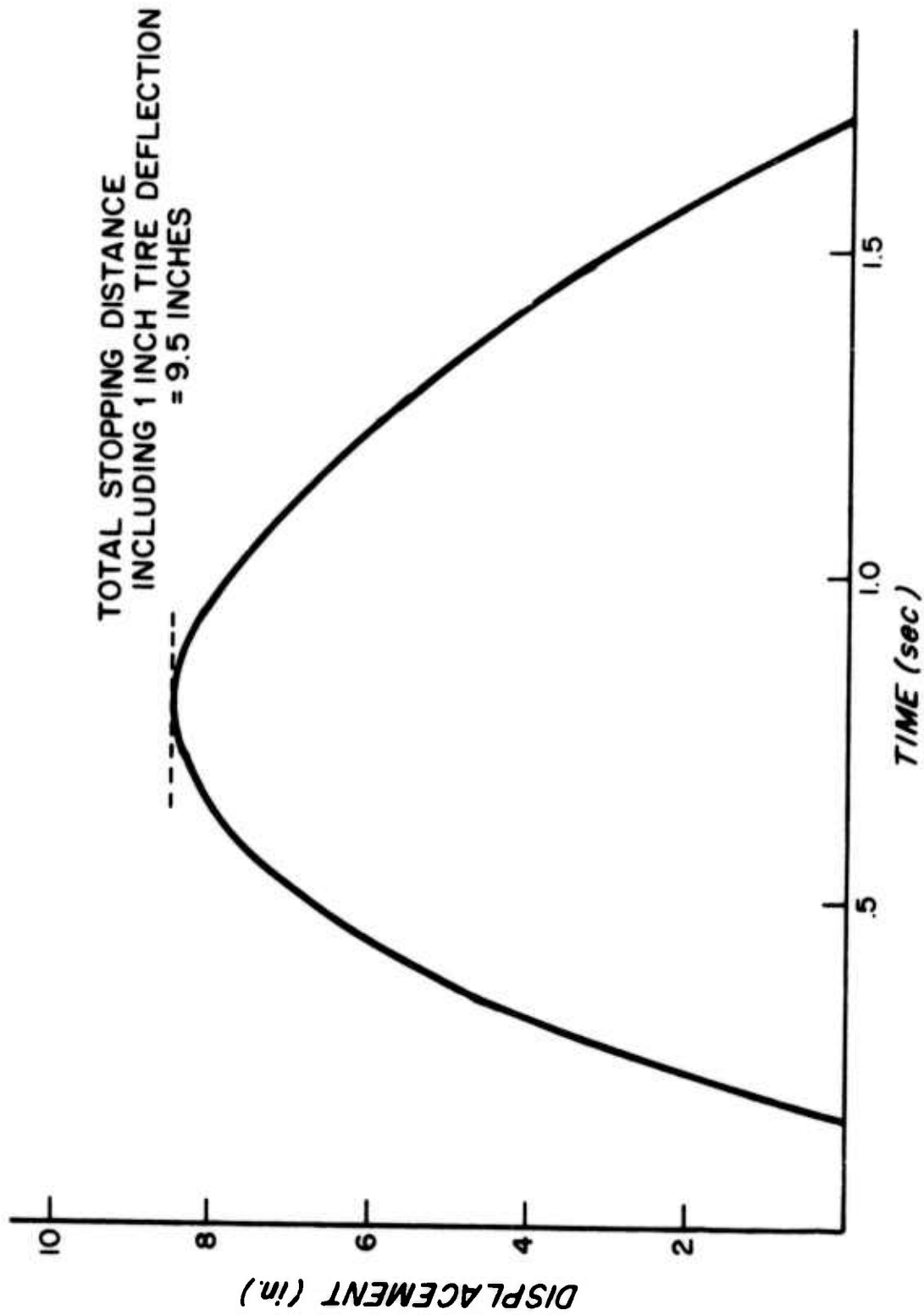


Figure 14. Example of Displacement-Time Curve for Energy Absorber on M-6 Tests at Norfolk, Virginia. August 1974. EERD-WHOI.

the bottom of the stroke. The hydraulic component of the strut was designed to provide a more constant force with a high viscous energy absorption capability. However, because the strut was mounted horizontally rather than vertically, the hydraulic circuitry was altered in an uncertain fashion resulting in less than designed viscous energy absorption. It should be noted that even under less than ideal mounting conditions, the assembly was still very effective as seen from the acceleration graph of Fig. 13.

Locating the contact level of the wheel with the ship above the center of gravity of the boat resulted in additional energy absorption capability. This geometry caused the boat C.G. and the bottom of the boat to move further towards the ship than the deck level because of induced roll. Thus, additional damping was provided by the rolling action and by the forced water motion between the ship and the boat. It is probable that secondary effects such as this will have considerable influence on final designs.

### MATERIALS, EQUIPMENT AND OTHER TECHNIQUES

There is a wide range of elastic materials and equipment available today that were not available a few decades ago. Hence, our freedom in modifying craft to be appropriately fendered is much greater than a few years ago.

These include rubbers and plastics in compression, shear and tension. Also these materials can be used for non-corrosive bearings that will take the physical and chemical abuse of seagoing operations.

The possibility of making combined plastic or rubber and oil-filled compression units that combine the best of spring and fluid compression and damping is also now within the state of the art. The requirements appear to be somewhere between the common present day practices in aviation and marine work.

The relative importance of incorporating more non-bounce capacity with proper oleo mechanisms to supplement the simple air or material spring reactive forces is certainly a topic for further study and test.

Obviously aircraft landing gear assemblies are neither mechanically practical nor technically practical for most boat applications except in the initial exploratory period. Several other techniques and concepts have been considered and suggested by various people. These include:

- (1) The substitution of a sliding spherical segment with appreciable radius to substitute for a castoring wheel. This would need a resilient backing to provide energy absorption.
- (2) The substitution of linkages for plungers to achieve thwartship motion with stronger and more trouble-free equipment.
- (3) A compound wheel with the rim made of small rubber rollers that have axles to prevent motion parallel to the principal axis. These are available commercially in small plastic units for passive conveyers.

- (4) A large rubber ball free to rotate in any direction like some small steel casters.  
(The details of this seem as complex as the principle seems simple.)
- (5) A castering resilient wheel assembly that utilizes compression on both the front and the back of the tire. (Several people involved believe that this method shows great promise.)

It would appear that for small motions of six inches or less, very simple resilient systems will do. If over a foot is needed, a more complex and perhaps foldable unit would probably be required. (Fig. 2)

### CONCLUSIONS AND RECOMMENDATIONS

- (1) The analogy between the energy-absorption approach problems of aircraft and boats appears to be a reasonable concept.
- (2) Several compromise designs between aviation methodology and modern marine fendering methodology appear reasonable and should be investigated.
- (3) As a training and educational process to acquaint fleet personnel with the potential of new techniques and the investigators as to other logistics requirements, the field tests were very successful.
- (4) Even six inches of energy absorption distance combined with a contact surface that can roll or slide smoothly would appear to be of considerable improvement over existing usage.
- (5) Under most conditions the bow assembly made a contact several times more frequently and at least twice as hard as the stern assembly. Some of this was due to operational procedures of the coxswain using the bow as a fender for the boat.
- (6) The virtual mass of the bow appeared to be only about a fourth of the virtual mass of the boat, but its thwartship motion was generally greater than of the stern.
- (7) A 5,500-pound capacity on the front assembly of the 60,000-pound M-6 boat accommodated horizontal velocities of about 2.5 feet per second which would seem reasonable for sea state three.
- (8) The articulated gangway ladder to a floating fender-platform as tried on the EL PASO appeared promising and should be given a more practical trial.
- (9) This work was believed to be meaningful but only exploratory in nature. Suggested further work would be along the lines of:
  - a) measurement and theory of boat motions alongside a ship in a seaway.
  - b) measurement and theory of boat motions in a landing ship's well.
  - c) design of combined roller-fender compatible with ship operations.

### ACKNOWLEDGEMENTS

The accomplishment of this much field testing with the limited resources within the contract was made possible only through the active cooperation of individuals from many organizations, commands, and ships.

Mr. Denzil Pauli of ONR assisted in many aspects of the frequent liaison work. Mr. William Baca of MASDIC at Davis Monthon Air Force Base at Tucson was most helpful in arranging inspection and procurement of surplus aircraft landing gear. Before, during, and after the tests, Mr. Clifford Stevens of the Annapolis Laboratory Division of the Naval Ship Research and Development Center gave sound advice and useful help.

Within COMPHIBLANT interest and assistance was forthcoming at many places and levels. The advice and help of Captain Kent Carroll (Chief of Staff), and Captain David Space (Chief of Staff for Engineering) made the overall planning possible and the detailed planning practical. The installation work at Norfolk was done by the AMSU group under Cmdr. Richard O'Donnell who also went to Davis Monthon Air Force Base to help select the most appropriate available wheel assemblies. At INSWARLANT where the units were mounted, special thanks are due Chief Warrant Davis and Chief Bush and his shop crew.

Aboard ships Captain Carroll of Squadron Ten and Captain Merrill of Squadron Two set the constructive tone of help from groups within their squadrons. Aboard ships and particularly aboard the FRANCIS MARION and SHREVEPORT the shop, deck, and boat personnel worked long and hard to install and maintain equipment and to conduct the tests. Particular thanks are due Lt. Cmdr. Frank James (Squadron Two Engineering Officer) who through his insight, enthusiasm, and efforts kept the work moving forward.

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